Internal Waves and Mixing in the Aegean Sea

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Grant Number: N00014-04-1-0238

LONG-TERM GOALS

To identify the major processes producing mixing in the upper ocean and to understand their dynamics sufficiently well to permit accurate parameterization of mixing for use in numerical models.

OBJECTIVES

This project was designed to understand how the very rugged and irregular bathymetry in the Aegean Sea modifies the internal wave field and the mixing it produces. Because tides are weak throughout the Mediterranean, mixing produced by internal waves should stand out, unlike the situation on the U.S. coasts, where tidal currents generate a significant fraction of the mixing. Going to a place where one of the two major processes is weak should allow us to understand better the role of internal waves, e.g., how much of the mixing observed close to sloping bottoms results from scattering of internal waves?

APPROACH

We used moorings and intensive microstructure and towed measurements to examine small-scale fields on the southern slope of the Cycladic Plateau, just west of Santorini in the central Agean (Fig. 1). Colleagues at the Hellenic Centre for Marine Research (HCMR) had previously obtained high-resolution bathymetry of the site, and fishing was not intense in the region. These provided excellent records of internal waves and mixing during the transition from summer to winter conditions in the Aegean. Tides are weak in the Aegean because the Mediterranean basin is much to small to resonate

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **Internal Waves And Mixing In The Aegean Sea**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th St,Seattle,WA,98105**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

with tidal forcing. During our intensive measurement HCMR colleagues conducted a hydrographic survey around us from their ship, the R/V Aegaeo.

WORK COMPLETED

Most of the analysis has been done for some time, but completion and publication has been delayed by the need to understand and document the noise level of our dissipation measurements. Below the shallow pycnocline stratification in the Aegean rapidly drops to abyssal levels. As a result, even very low dissipation rates correspond to large diapycnal diffusivities. This effort is nearly completed.

RESULTS

The work area (Fig. 1) was selected for its steep bathymetry and low level of fishing. Most of our data were taken with Advanced Microstructure Profilers (AMPs). Several grids were used, some up and down slope, others along slope, and another as radial lines crossing the small seamount centered at 36.45 N, 25.1 W. Time series of current and stratification from the moorings as well as a synoptic survey by Greek colleagues provide background for interpreting the turbulence.

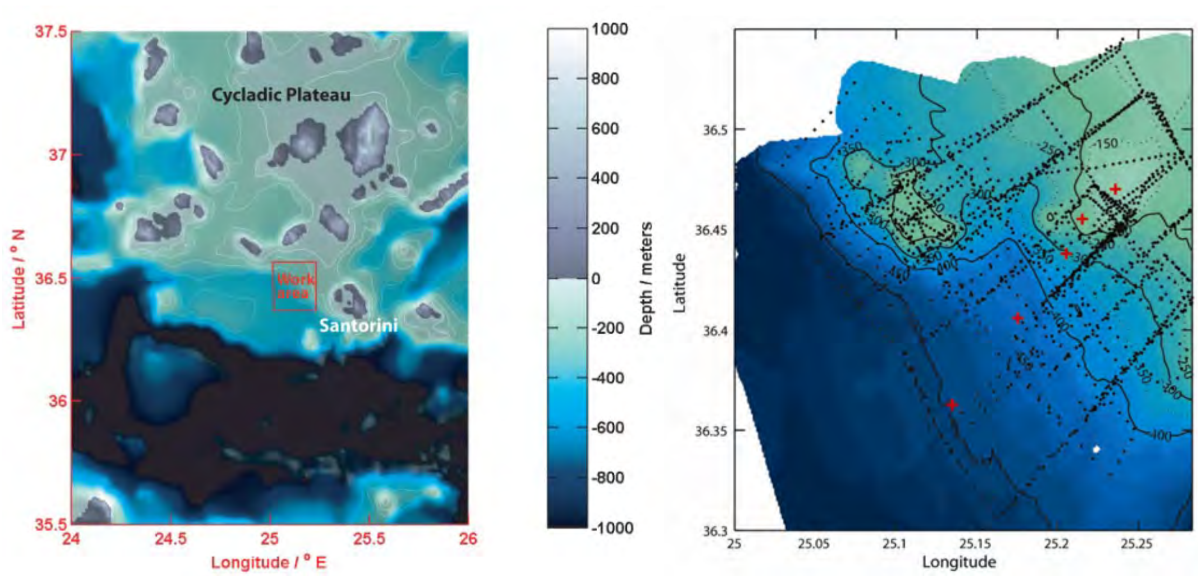

Figure 1. Bathymetry of the south side of the Cycladic Plateau in the Aegean Sea (left) and (right) positions of AMP drops (black dots) and moorings (red crosses) in the work area. Isobaths are labed with meters. From north to south, the moorings were a 300 kHz WorkHorse set on the bottom at 110 m, Moored Profilers at 180 m, 300 m and 420 m, and a LongRanger 75 kHz at 500 m.

Begun on 27 October 2004, the turbulence measurements fortuitously caught the very rapid transition from summer to winter conditions in the Aegean. Cold air and increased winds deepened the surface mixed layer from 40 to 70 m while we were in the area (Fig. 2) and provided a changing background for the turbulence.

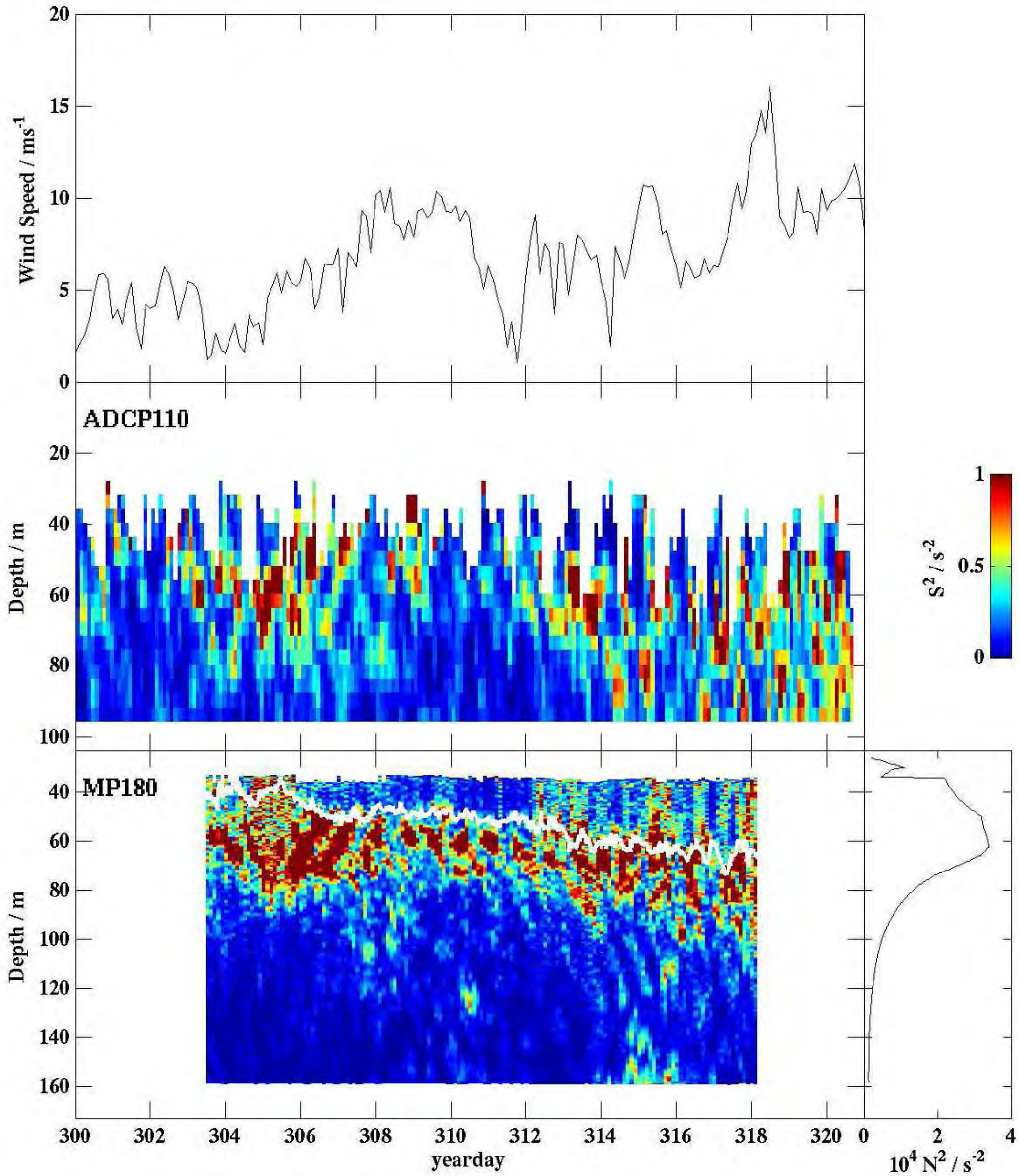

Figure 2. Top) wind speed, Middle) shear-squared measured with the WorkHorse 300 kHz ADCP on the bottom at 110 m, and Bottom) shear-squared and stratification (N^2) measured with the Moored Profiler moored at 180 m. The observations caught the rapid transition from summer to winter and the accompanying increase in shear-squared at the base of the mixed layer (white line in MP180 panel) that deepened the layer. The ragged upper boundary of the 300 kHz record resulted from the daily migration of the scattering layer.

Initially, dissipation rates dropped rapidly with depth below the pycnocline beneath the mixed layer, except around a small seamount on the continental slope at the west end of the work area and in a density current traveling along isobaths just upslope from the seamount (Fig. 3). Although dissipation rates were modest in these two regions, 10^{-9} to 10^{-8} W/kg, owing to the weak stratification the diapycnal diffusivities were fairly large, 10^{-4} to 10^{-3} m^2/s. Elsewhere below the pycnocline dissipation rates were close to 10^{-10} W/kg, the level we have long defined as our noise level. Even these, however, correspond to diffusivities close to 10^{-5} m^2/s, the background level in the open-ocean thermocline. This in turn has forced us to examine how we define our noise levels, a job far more difficult than expected but nearly complete.

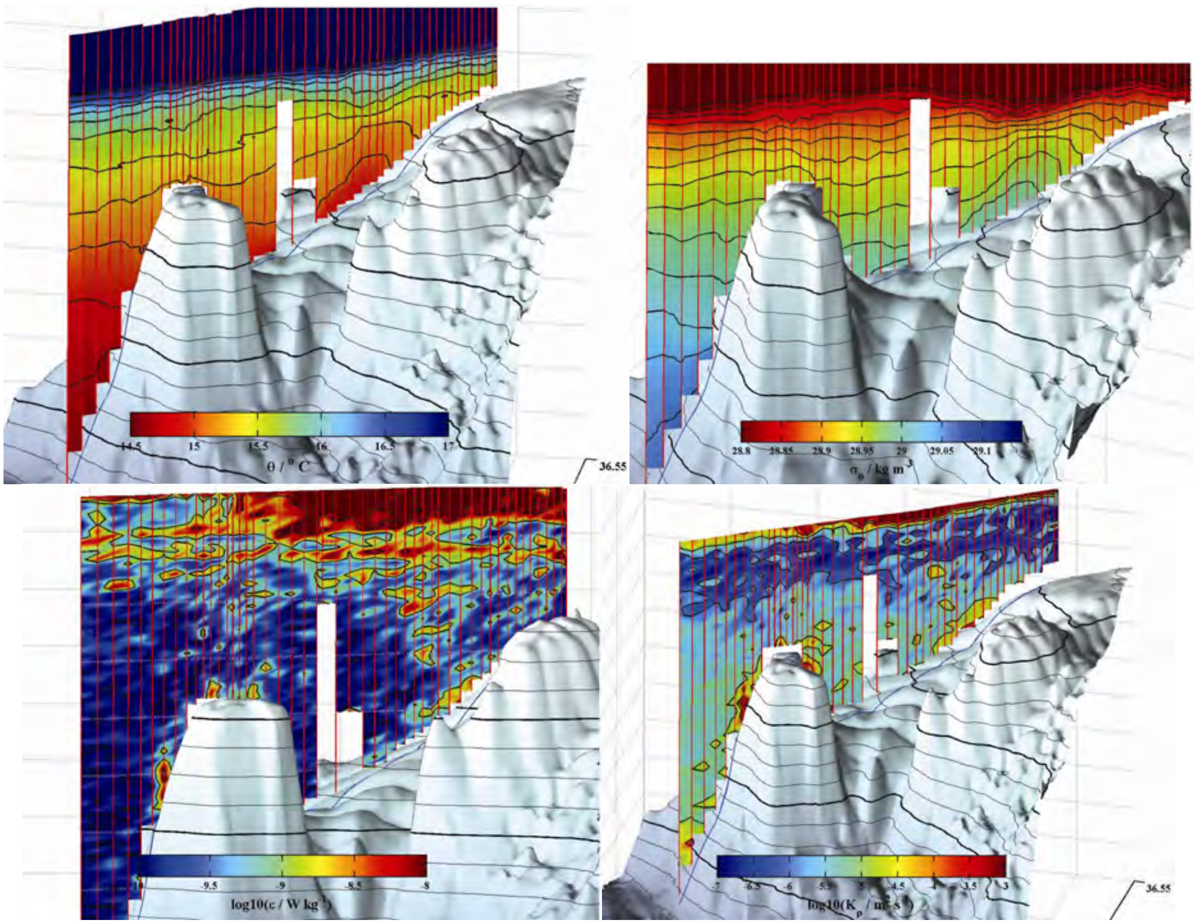

Figure 3. AMP section downslope and across a small seamount. Upper left) temperature, Upper right) Potential density, Lower left) Logarithm of the dissipation rate, and Lower right) Logarithm of diapycnal diffusivity. Vertical red lines are position of AMP profiles. Isobath contours are at 25 m intervals with hundreds made darker. Temperature and density contours reveal a density current flowing along the isobaths. It is one of the few places with strong diffusivity.

Shear-squared below the pycnocline increased in response to the rising winds, as seen in the MP180 panel of Figure 2. The effect on diapycnal diffusivity is shown in Figure 4 which compares two AMP lines along the same cross-slope line. Within about 100 m of the slope dissipation rates during yday 314 were about ten times those during yday 302. Once we have final dissipation rate, we will attempt to determine how much of the increase resulted from downward propagation of shear and how much from scattering from the sloping bottom.

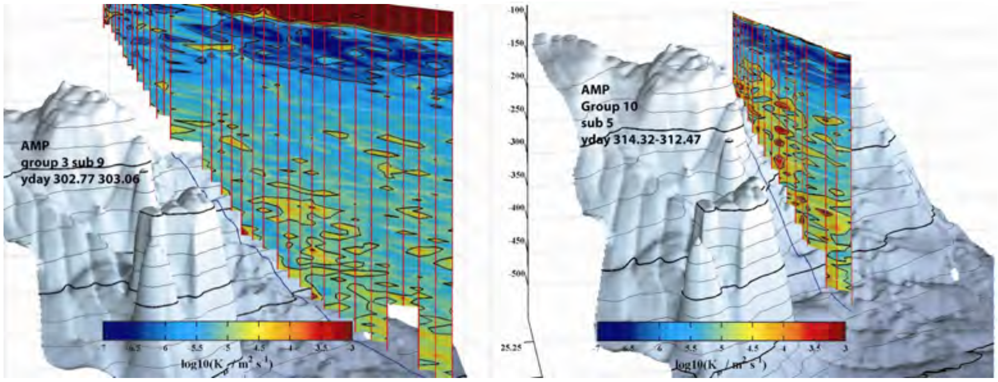

Figure 4. Increase in the logarithm of diapycnal diffusivity along the downslope section between yday 302.9 (left) and yday 314.4 (right), apparently in response to the increase in wind speed (Fig. 1).